***IO VOLCANO OBSERVER (IVO)*: DOES IO HAVE A MAGMA OCEAN?.** A. S. McEwen[1], and the IVO Science Team. [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ.

Introduction: The *IVO* Discovery mission concept is focused on understanding tidal heating as a fundamental planetary process. Essential to this goal is understanding the internal structure of Io, especially whether or not there is a magma ocean. *IVO* will acquire a suite of measurements to address this question via a set of ten close flybys of Io.

Background: Peale *et al.* [1] predicted that Io would have a thin lithosphere over a magma ocean, with heat loss via conduction, but *Voyager 1* revealed tall mountains that appear to be uplifted blocks of crust, requiring a thick, rigid lithosphere. The tidal heat from within Io is hypothesized to instead come to the surface via the advection (bulk transport) of magma through the lithosphere in what is called a "heat-pipe" mechanism [2] (see Figure 1). While radically different from how other bodies in the Solar System operate today, this same process is expected to operate on any planetary body with a magma ocean, including the early Earth [3], the Moon and other terrestrial planets, and tidally heated exoplanets [4].

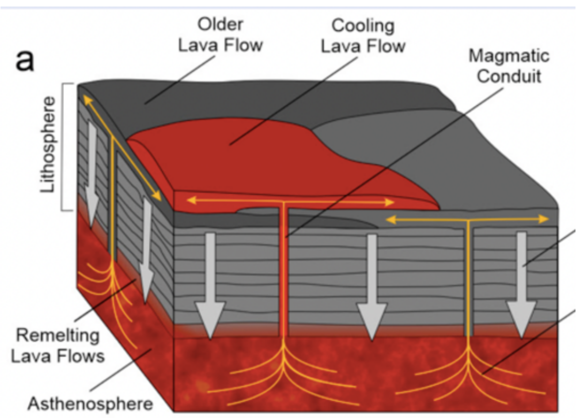


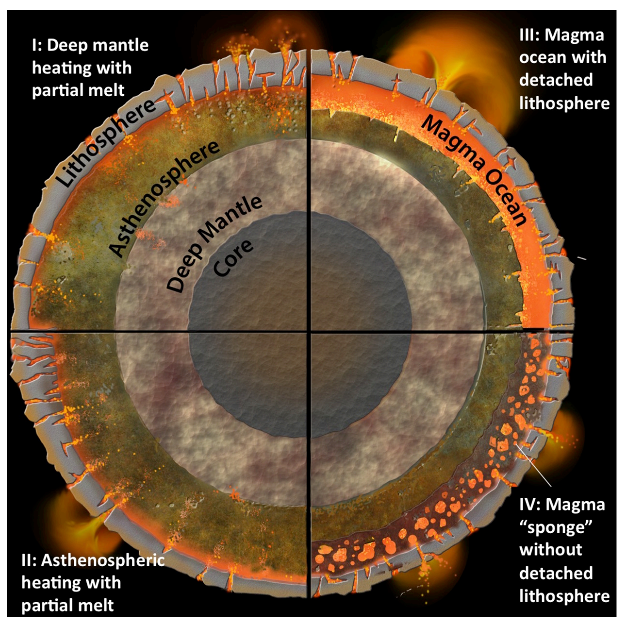
Fig. 1. Heat Pipe mechanism for heat transfer in Io.

Galileo results suggested that some of Io's lavas are hotter than any recent eruptions on Earth [5]. Such lavas were likely prevalent on the early Earth, Moon, Mars, Venus, and Mercury and have been suggested to be active today on close, eccentric "super-Earths" in exoplanetary systems. Such high-temperature eruptions are expected if the mantle undergoes significant melting, consistent with a magma ocean.

Objective A1 of *IVO* is to determine the degree and distribution of melt in Io's mantle. The early evolution of many Solar System bodies was dominated by the formation and solidification of a *magma ocean*—a layer, on the surface or in the interior, that has such a high melt fraction that it behaves like a fluid. Tidal heating may maintain such a magma ocean inside present-day Io, though the science community has not reached agreement about its existence [6]. The leading alternative is partial melt in Io's mantle, which rises and erupts rather than forming a magma ocean [7]. An intermediate degree of melting is also considered (Box 1, hypothesis IV), but would need to overcome the expected rapid segregation of the liquid and solid phases [8, 9].

Box 1. Testing Models for tidal heating and melt distribution in Io: IVO will test four leading hypotheses (see Table). Combinations of these models are possible, such as I + II mix, or components of I and/or II along with III or IV. An unexpected result such as high k_2 plus small libration amplitude disproves the heat-pipe model.

Model	Tidal k_2	Libration amplitude	Magnetic induction	Major Lava	Heat Flow
I	low	small	weak	High-T basaltic	More polar
II	low	small	weak	Basaltic	More equatorial
III	high	large	strong	Very high-T ultramafic	Equatorial or uniform
IV	low	small	strong		



The magnetic induction interpretation of Khurana *et al.* [10] requires at least 20% melt in Io's upper mantle, and this result has been confirmed by a recent independent study [11]. However, another study [12] found that plasma interactions in an asymmetric atmosphere could mimic the induction signature. *IVO* will address these issues with better data on Io's plasma environment, flybys optimized to the best times and places for measuring variations in the magnetic field, and new laboratory measurements of electrical conductivities of relevant planetary materials.

If Io has a detached lithosphere over a global magma ocean, then two independent measurements should provide definitive evidence. One of these is tidal k_2, the ratio of imposed gravitational potential from Jupiter (which is well known) and the induced gravitational potential from the deformation of Io (to be measured by *IVO*). The second measurement is libration amplitude of Io [13]. Furthermore, these measurements together (and further constrained by the magnetic induction data) provide a strong constraint on lithospheric thickness and rigidity, a key test of the heat pipe model (Figure 2).

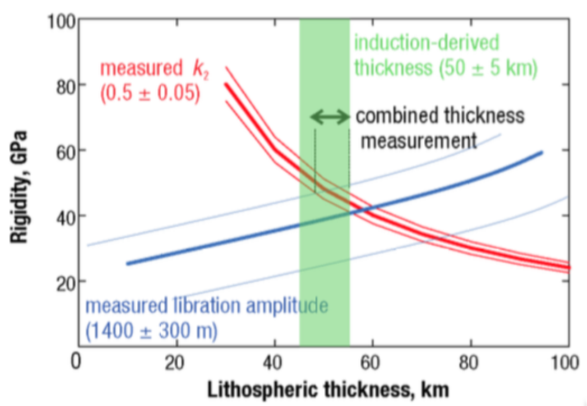


Fig. 2. ***IVO can precisely determine average lithospheric thickness and rigidity if Io has a magma ocean.*** *Example measurements of k_2, libration, and magnetic induction.*

Global maps of heat flow and volcanic and tectonic features on Io, and measurement of lava temperatures and compositions, will provide additional data to interpret whether Io has a magma ocean.

Mission Architecture: The basic design is similar to the previous *IVO* concept [14]. The spacecraft will orbit Jupiter at an inclination of ~45°, minimizing total radiation dose to ~20 krad per flyby, and *IVO*'s total dose over 10 orbits will be less than one tenth that of *Europa Clipper*. The geometry and timing of each Io encounter (Fig. 3) has been carefully designed to accomplish the science objectives.

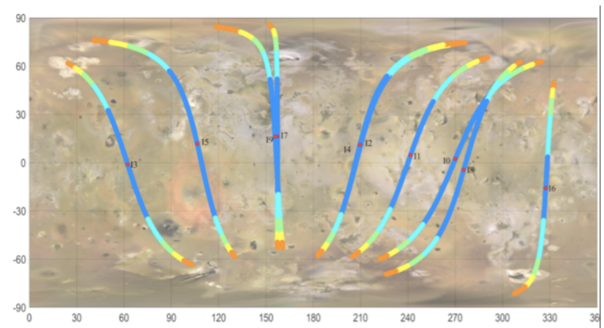


Fig. 3. Plot of IVO groundtracks over Io during closest approach, color-code by range (blue indicates <1000 km).

Science instruments include a narrow-angle camera nearly identical to that of the Europa Imaging System [15], the Plasma Instrument for Magnetic Sounding [16], dual fluxgate magnetometers from multi-mission heritage at UCLA [e.g., 17], a thermal mapper with heritage from *Bepi-Colombo* [18], and a neutral mass spectrometer in development for *JUICE* [19]. In Phase A we will propose a student collaboration wide-angle stereo camera.

References: [1] Peale, S.J. et al. (1979) Science 203, 892–894. [2] O'Reilly, T. C., and G. F. Davies (1981) *Geophys. Res. Lett.* **8**:313–316. [3] Stern, R. J. (2018) *Phil. Trans. R. Soc. A* **376**:20170406. [4] Moore, W. B., J. I. Simon, and A. G. Webb (2017) *Earth Planet. Sci. Lett.* **474**:13–19. [5] McEwen, A.S. et al. (1998) Science 281, 87. [6] de Kleer, K. et al. (2019) https://www.kiss.caltech.edu/workshops/tidal_heating/tidal_heating.html. [7] Keszthelyi, L. et al., this conference. [8] Stevenson, D. (1989) *Geophys. Res. Lett.* **16**:1067–1070. [9] Kohlstedt, D. L., and B. K. Holtzman (2009) *Annu. Rev. Earth Planet. Sci.* **37**:561–593. [10] Khurana, K.K. et al. (2011) Science 332, 1186–1189. [11] Šebek, O., P. M. Trávní ek, R. J. Walker, and P. Hellinger (2019) *J. Geophys. Res.* **124**:313–341. [12] Blöcker, A. et al. (2018) JGR SP, 9286–9311. [13] Van Hoolst, T. et al. (2018) Fall AGU abstract P51E- 2929. [14] McEwen, A.S. et al. (2014) Acta Astron. 93, 539. [15] Turtle, E.P. (2016) 3rd Int. Workshop Instr. Planet. Mission., LPI Contr. 1980, 4091. [16] Westlake, J.H. et al. (2016) 3rd Int. Workshop Instr. Planet. Mission., LPI Contr. 1980, 4037. [17] Banfield, D. et al (2019) Space Sci. Rev. 215, article 4, 33 pp. [18] Hiesinger, H. et al. (2007), PSS 58, 144–165. [19] Wurz, P. et al. (2018) EGU2018, 10091.